SUPER-RESOLUTION DISPLAY

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/094,962, filed Jul. 31, 1998, the entire teachings of which are incorporated herein by reference.

GOVERNMENT SUPPORT

The invention was supported, in whole or in part, by a grant N00014-96-1-1228 from ONR/DARPA. The Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

People love to observe pictures and images displayed all around them. The bigger, the brighter, the higher resolution, and the more inexpensive these displays are the better. The future promises digital cinema and immersive virtual reality systems that provide a realistic visual experience. While the computational power necessary to make these systems a reality is available, high-quality large-scale displays are not.

Typically, computer-generated images are stored as bitmaps in memory. A picture element, or pixel, is represented by three bytes in the bitmap representing color intensities for the red, green and blue values of the pixel. To display the image, the bitmap is stored in a special, high-speed memory called a frame buffer which is accessed by the display hardware. The display hardware may then, from the image stored in the frame buffer, create a composite analog video signal, or separate red, green and blue (RGB) video signals, or whatever type of signal is appropriate for the display.

Current display technology is largely based on the cathode ray tube, the last remaining hot cathode vacuum electronic element in modem computer systems. Resolutions on displays built using this technology are limited by the required precision analog electronics and the achievable bandwidths of high energy video circuitry to 1200×1600 pixels for off the shelf displays, and to 4000×4000 pixels for research prototypes.

Liquid crystal displays are gradually replacing CRTs in portable applications with dramatic improvements in power, but the resolution remains limited to the 1600×1200 pixel range for even high end prototypes.

High performance projection displays exhibit similar resolution limitations, partly due to the large fill factor of the pixel elements required for high optical efficiency. Even the micro-mirror technologies based on micromechanical deflection systems appear (perhaps for market reasons) to be limited to relatively low resolution.

Various aspects of a projection system, such as the optics, defects in the projection screen, the projection angle relative to the screen, etc. can introduce various types of distortion into a displayed image. These include pincushion and barrel distortion which appear as the bowing inward and outward respectively of square objects. Keystoning and trapezoidal distortion results when the projection angle is not perpendicular to the screen angle. Lateral and rotational displacement of the image is directly due to similar displacement of the projector.

Throughout the history of display design, the focus has been on constructing ever larger, higher brightness single display elements. The optical quality, alignment, precision, and perfection in manufacturing these displays has progressed enormously over the past 25 years, but we are still faced with the essential limitation of low resolution of the display array.

A key technological trend of the past 20 years has been the dramatic reduction in the price of computation. The present invention exploits this cost reduction by replacing high precision optical and mechanical assembly with increased computation. As the price of computation continues to drop, this tradeoff increasingly favors computation over precision assembly.

The problems that need to be overcome to make a scalable technology for seamless large-scale displays are elucidated by discussing the prior work in this field. Three well-known technologies are single projector, discrete tiling, and edge-blended projector arrays.

Single projector technology for large-scale displays uses a single optical system and display source to project a large-scale display. While this approach provides a seamless picture, it is not physically scalable. The resolution of such a system is limited to the resolutions of projectors that are available. The resolutions available are determined by the media formats commonly available, for example, NTSC through HDTV from the television industry, and VGA through XGA from the notebook computer industry. To obtain a larger projected image, the distance of the projected image from the projector is increased. The resulting image is larger, but the resolution is constant and brightness decreases inversely with the increase in area projected. Currently there are three types of systems in common use: cathode ray tube based systems, light-valve based (DMD, LCD, ILA) systems, and laser projection systems, discussed below.

Cathode ray tube technology is well understood. Brightness and contrast ratios for these systems are reasonable, and the resolutions available are sufficient for a 60-inch rear-projection screen. The main disadvantages are that building a larger system requires custom built cathode ray tubes to create the appropriate resolution and brightness. In addition, such systems are subject to phosphor burn-in and drift. The best systems available on the market for wide distant viewing require that the displayed images be dynamic to avoid phosphor burn-in, whereby the phosphor surface is physically damaged by other ions where the electrons are supposed to impinge.

Furthermore, color systems using this technology have three separate guns which produce the additive red, green and blue. These guns must be manually converged; however, the convergence typically drifts out of alignment after a month of use. In summary, these disadvantages present problems with scalability of resolution and brightness, and recurrent maintenance problems for maintaining convergence.

Light-valve based systems modulate light to represent each pixel. Such a system uses a light-valve to reflect or transmit light from a light source, based on the intensity of the pixel represented by a particular valve. The light valves are typically liquid crystal displays (LCD), or digital micro-mirror device arrays (DMD), or image light amplifiers (ILA). Each of these systems suffers commercially in the consumer market because costs are higher than pure CRT-based systems. An advantage of light-valves over CRT systems is that they do not suffer from the analog drift and can be made very bright. In terms of scaling these technologies up for resolution and brightness for larger images, there are still fundamental physical concerns. Custom designing a new light-valve for every situation is not possible. Additionally, since only a single light source is typically involved, one would have to search for other solutions when the limits of single bulb technology are hit, though that is not the current constraint.